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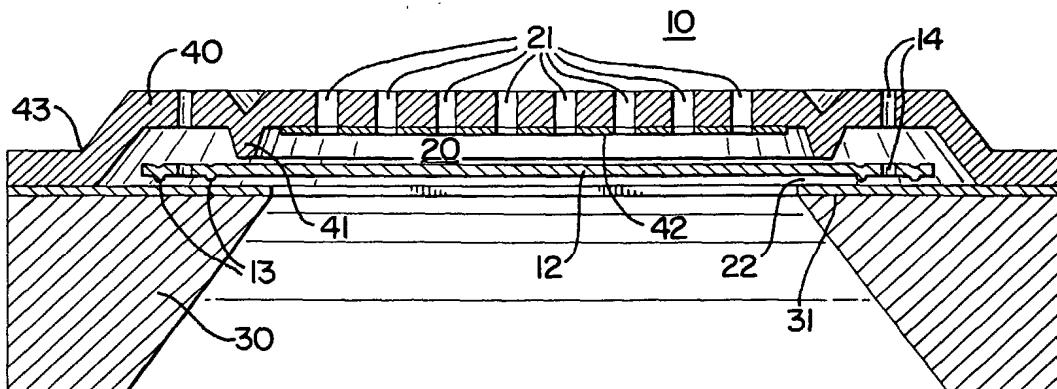
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(57) **Abstract:** Multiple embodiments of solid state micro-structures, such as a condenser microphone, are disclosed. According to one embodiment, the transducer a fixed perforated member, a freely movable diaphragm spaced from the perforated member, a support ring in the perforated member maintaining the proper spacing between the diaphragm and the perforated member near the perimeter; and compliant suspension springs allowing the diaphragm to rest freely on the support ring and yet mechanically decouples the diaphragm from the perforated member. According to another embodiment, a raised micro-structure is disclosed for use in a silicon based device. The raised micro-structure comprises a generally planar film having a ribbed sidewall supporting the film.



For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

MINIATURE BROADBAND TRANSDUCER

DESCRIPTION

TECHNICAL FIELD

The present invention relates to miniature silicon transducers.

BACKGROUND OF THE INVENTION

• The use of silicon based capacitive transducers as microphones is well known in the art. 5 Typically, such microphones consist of four elements: a fixed backplate; a highly compliant, moveable diaphragm (which together form the two plates of a variable air-gap capacitor); a voltage bias source and a buffer.

The batch fabrication of acoustic transducers using similar processes as those known from the integrated circuit technology offers interesting features with regard to production cost, 10 repeatability and size reduction. Furthermore, the technology offers the unique possibility of constructing a single transducer having a wide bandwidth of operation with a uniform high sensitivity. This provides for a transducer that, with little or no modification, can be used in such diverse applications as communications, audio, and ultrasonic ranging, imaging and motion detection systems.

15 The key to achieve wide bandwidth and high sensitivity lies in creating a structure having a small and extremely sensitive diaphragm. Designs have previously been suggested in U.S. Patent No. 5,146,435 to Bernstein, and in U.S. Patent. No. 5,452,268 to Bernstein. In these structures the diaphragm is suspended on a number of very flexible movable springs. However, the implementation of the springs leads to an inherent problem of controlling the acoustic leakage in the structure, 20 which in turn affects the low frequency roll-off of the transducer. Another approach is to suspend the diaphragm in a single point, which also provides an extremely sensitive structure. See U.S. Pat. No. 5,490,220 to Loeppert. Unfortunately, in this case the properties of the diaphragm material become critical, especially the intrinsic stress gradient which causes a free film to curl. Eventually, this leads to a similar problem for this structure concerning the reproducibility of the low frequency 25 roll-off of the transducer.

The two mechanical elements, the backplate and diaphragm, are typically formed on a single silicon substrate using a combination of surface and bulk micromachining well known in the art.

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One of these two elements is generally formed to be planar with the surface of the supporting silicon wafer. The other element, while itself generally planar, is supported several microns above the first element by posts or sidewalls, hence the term "raised microstructure."

In general, the positioning of the two elements with respect to each other affects the 5 performance of the entire device. Intrinsic stresses in the thin films comprising the raised microstructure cause the structure to deflect out of the design position. In a microphone in particular, variations in the gap between the diaphragm and backplate affect the microphone sensitivity, noise, and over pressure response.

Many other factors also affect the manufacture, structure, composition and overall design 10 of the microphone. Such problems are more fully discussed and addressed in U.S. Patent No. 5,408,731 to Bergqvist; U.S. Patent No. 5,490,220 to Loepert, and U.S. Patent No. 5,870,482 to Loepert.

In the specific example of the design of a microphone backplate as a raised microstructure, the goal is to create a stiff element at a precise position relative to the diaphragm. One method to 15 achieve this is to form the backplate using a silicon nitride thin film deposited over a shaped silicon oxide sacrificial layer which serves to establish the desired separation. This sacrificial layer is later removed through well known etch processes, leaving the raised backplate. Intrinsic tensile stress in the silicon nitride backplate will cause it to deflect out of position. Compressive stress is always avoided as it causes the structure to buckle.

FIG. 12 depicts one such raised microstructure 110 of the prior art. After the oxide is 20 removed leaving the raised microstructure 110, an intrinsic tension will be present within the plate 112. This tension **T** results from the manufacturing process as well as from the difference between the coefficient of expansion of the material of the raised microstructure 110 and the supporting wafer 116. As shown, the tension **T** is directed radially outwards. The tension **T** intrinsic in the 25 plate 112 will result in a moment as shown by arrow **M** about the base 118 of sidewall 114. This moment **M** results in a tendency of the plate 112 to deflect towards the wafer 116 in the direction of arrow **D**. This deflection of plate 112 results in a negative effect on the sensitivity and performance of the microphone.

A number of undesirable means to negate the effects of this intrinsic tension within a thin-film raised microstructure are known in the prior art. Among them are that the composition of the 30 thin film can be adjusted by making it silicon rich to reduce its intrinsic stress levels. However, this

technique has its disadvantages. It results in making the thin film less etch resistant to HF acid, increasing the difficulty and expense of manufacture. An additional solution known in the prior art would be to increase the thickness of the sidewall supporting the raised backplate thereby increasing the sidewall's ability to resist the intrinsic tendency of the thin film to deflect. While this sounds acceptable from a geometry point of view, manufacture of a thick sidewall when the raised microstructure is made using thin film deposition is impractical.

5 The object of the present invention is to solve these and other problems.

SUMMARY OF THE INVENTION

One aspect of the present invention results from a realization that a diaphragm has the highest mechanical sensitivity if it is free to move in its own plane. Furthermore, if the diaphragm is resting on a support ring attached to the perforated member, a tight acoustical seal can be achieved leading to a well controlled low frequency roll-off of the transducer. Additionally, if a suspension method is chosen such that the suspension only allows the diaphragm to move in its own plane and does not take part in the deflection of the diaphragm to an incident sound pressure wave, complete decoupling from the perforated member can be achieved which reduces the sensitivity to external stresses on the transducer.

In one embodiment, the present invention features an acoustic transducer consisting of a perforated member and a movable diaphragm spaced from the perforated member. The spacing is maintained by a support ring attached to the perforated member upon which the diaphragm rests. There are means for suspending the diaphragm such that the diaphragm is free to move in its own plane, thereby maximizing the mechanical sensitivity of the diaphragm. The suspension is achieved by restraining the diaphragm laterally between the support ring and the substrate attached to the perforated member. There are means for applying an electrical field between the perforated member and the diaphragm. There are also means for detecting the change of electrical capacitance between the perforated member and the diaphragm as the diaphragm deflects due to an incident acoustic sound pressure wave.

20 The thickness and size of the diaphragm are chosen such that the resonance frequency of the diaphragm is larger than the maximum acoustical operating frequency. Similarly, the dimensions of the perforated member are chosen such that the resonance frequency is larger than the maximum acoustical operating frequency. The perimeter at which the perforated member is attached to the substrate can optionally be shaped to minimize the curvature of the perforated member due to

intrinsic stress in said perforated member. The suspension means of the diaphragm are made such that minimal mechanical impedance exists in the plane of the diaphragm, and yet maintains the close spacing of the diaphragm to the perforated member. The support ring is formed in the perforated member and sets the size of the active part of the diaphragm. The height of the support 5 ring defines the initial spacing between the diaphragm and the perforated member. There are one or more openings in the diaphragm and perforated member, providing an acoustical path from the back chamber of the transducer to the surroundings thereby eliminating any barometric pressure from building up across the diaphragm. The low roll-off frequency of the transducer is limited by the corner frequency formed by the acoustical resistance of said openings and the narrow gap 10 between the diaphragm and substrate in combination with the acoustical compliance of the transducer back chamber. The perforated member has a systematic pattern of openings providing a low acoustical resistance of the air flowing to and from the air gap between the movable diaphragm and the perforated member. The systematic pattern and size of the openings are chosen such that the high roll-off frequency of the transducer is limited by the corner frequency introduced 15 by the acoustical resistance in combination with the acoustical compliance of the diaphragm and back chamber of the transducer. This acoustical resistance is largely responsible for the acoustic noise generated in the device. As will be appreciated by those having skill in the art, there is a tradeoff to be made between damping and noise.

The perforated member, support ring, suspension means, and diaphragm can be made from 20 a silicon wafer using micro machining thin-film technology and photolithography and can be made of one or more materials from the group consisting of: carbon-based polymers, silicon, polycrystalline silicon, amorphous silicon, silicon dioxide, silicon nitride, silicon carbide, germanium, gallium arsenide, carbon, titanium, gold, iron, copper, chromium, tungsten, aluminum, platinum, palladium, nickel, tantalum and their alloys.

In another embodiment the present invention also features an acoustic transducer consisting 25 of a perforated member and a movable diaphragm spaced from the perforated member. The spacing is maintained by a support ring attached to the perforated member upon which the diaphragm rests. There are means for suspending the diaphragm such that the diaphragm is free to move in its own plane, thereby maximizing the mechanical sensitivity of the diaphragm. The suspension is achieved 30 by utilizing high compliance springs between the diaphragm and perforated member. The spring

assists in the construction and diaphragm release process, but once in operation the electrostatic attraction brings the diaphragm into contact with the perforated member support structure. Contrary to that taught by U.S. Patent No. 5,146,435 to Bernstein, and U.S. Patent No. 5,452,268 to Bernstein, the spring of the present invention plays an insignificant role in establishing the diaphragm compliance. There also are means for applying an electrical field between the perforated member and the diaphragm. There are further means for detecting the change of electrical capacitance between the perforated member and the diaphragm as the diaphragm deflects due to an incident acoustic sound pressure wave.

The thickness and size of the diaphragm is chosen such that the resonance frequency of the diaphragm is larger than the maximum acoustical operating frequency. Similarly, the dimensions of the perforated member are chosen such that the resonance frequency is larger than the maximum acoustical operating frequency. The perimeter at which the perforated member is attached to the substrate can optionally be shaped to minimize the curvature of the perforated member due to intrinsic stress in said perforated member. The high compliance suspension springs are made rigid enough for the structure to be made by micro machining technology, and yet compliant enough to mechanically decouple the diaphragm from the perforated member and to ensure that the in-plane resonance frequency of the diaphragm and springs is as small as possible compared to the intended low roll-off frequency of the transducer to prevent in-plane vibration of the diaphragm in operation. The support ring is formed in the perforated member and sets the size of the active part of the diaphragm. The height of the support ring defines the initial spacing between the diaphragm and the perforated member. There are one or more openings in the support ring, providing an acoustical path from the back chamber of the transducer to the surroundings thereby eliminating any barometric pressure from building up across the diaphragm. The low roll-off frequency of the transducer is limited by the corner frequency formed by the acoustical resistance of the openings and the acoustical compliance of the back chamber. The perforated member has a systematic pattern of openings providing a low acoustical resistance of the air flowing to and from the air gap between the movable diaphragm and the perforated member. The systematic pattern and size of the openings are chosen such that the high roll-off frequency of the transducer is limited by the corner frequency introduced by the acoustical resistance in combination with the acoustical compliance of the diaphragm and back chamber of the transducer. The perforated member, support ring, suspension

means, and diaphragm can be made from a silicon wafer using micro machining thin-film technology and photolithography and may be made of one or more materials from the group consisting of: carbon-based polymers, silicon, polycrystalline silicon, amorphous silicon, silicon dioxide, silicon nitride, silicon carbide, germanium, gallium arsenide, carbon, titanium, gold, iron, copper, chromium, tungsten, aluminum, platinum, palladium, nickel, tantalum and their alloys.

Another aspect of the present invention provides an improvement to raised microstructures for use in silicon based devices. In accord with one embodiment of this aspect of the present invention, a raised microstructure for use in a silicon based device is provided comprising a generally planar thin-film and a sidewall supporting the film, wherein the sidewall is ribbed.

Other features and advantages of the invention will be apparent from the following specification taken in conjunction with the following drawings.

BRIEF DESCRIPTION OF THE DRAWINGS:

FIG. 1 is an enlarged schematic cross-sectional view taken along the line 1-1 in FIG. 2 of an acoustic transducer with clamped suspension in accordance with the present invention;

FIG. 2 is a top plan view, partially in phantom, of the acoustic transducer of FIG. 1;

FIG. 3 is a cross-sectional perspective view of the acoustic transducer of FIG. 2 taken along line 3-3 of FIG. 2;

FIG. 4 is an enlarged partial top view, partially in phantom, of an acoustic transducer similar to FIG. 2 wherein the perforated member includes an optionally shaped attach perimeter;

FIG. 5 is an enlarged schematic cross-sectional view taken along the plane 5-5 in FIG. 6 of an acoustic transducer with high compliance spring suspension in accordance with the present invention;

FIG. 6 is a top plan view, partially in phantom, of the acoustic transducer of FIG. 5;

FIG. 7 is a cross-sectional perspective view of the acoustic transducer of FIG. 6 taken along plane 7-7;

FIG. 8 is a greatly enlarged partial top view, partially in phantom, of an acoustic transducer similar to FIG. 5 wherein the perforated member includes an optionally shaped attach perimeter;

FIG. 9 is an electrical circuit for the detection of the change of the microphone capacitance while maintaining a constant electrical charge on the microphone;

FIG. 10 is an electrical circuit for the detection of the change of the microphone capacitance while maintaining a constant electrical potential on the microphone;

FIG. 11 is a cross-sectional perspective view of the acoustic transducer of FIG. 4;

FIG. 12 is a cross sectional schematic of a raised microstructure known in the prior art;

FIG. 13 is a cross sectional perspective view of a raised microstructure embodying the present invention;

5 FIG. 14 is a cross section of the raised microstructure of FIG. 13; and

FIG. 15 is a plan view of FIG. 13, taken along line 11-11.

DETAILED DESCRIPTION OF THE INVENTION:

While this invention is susceptible of embodiment in many different forms, there is shown in the drawings and will herein be described in detail preferred embodiments of the invention with the understanding that the present disclosure is to be considered as an exemplification of the principles of the invention and is not intended to limit the broad aspect of the invention to the embodiments illustrated.

Referring now to the drawings, and particularly to FIGS. 1-3, an acoustic transducer in accordance with the present invention is disclosed. The acoustic transducer **10** includes a conductive diaphragm **12** and a perforated member **40** supported by a substrate **30** and separated by an air gap **20**. A very narrow air gap or width **22** exists between the diaphragm **12** and substrate **30** allowing the diaphragm to move freely in its plane, thereby relieving any intrinsic stress in the diaphragm material and decoupling the diaphragm from the substrate. A number of small indentations **13** are made in the diaphragm to prevent stiction in the narrow gap between the diaphragm and substrate. The lateral motion of the diaphragm **12** is restricted by a support structure **41** in the perforated member **40**, which also serves to maintain the proper initial spacing between diaphragm and perforated member. The support structure **41** may either be a continuous ring or a plurality of bumps. If the support structure **41** is a continuous ring, then diaphragm **12** resting on the support structure **41** forms tight acoustical seal, leading to a well controlled low frequency roll-off of the transducer. If the support structure **41** is a plurality of bumps, then the acoustical seal can be formed either by limiting the spacing between the bumps, by the narrow air gap **22**, or a combination thereof.

The conducting diaphragm **12** is electrically insulated from the substrate **30** by a dielectric layer **31**. A conducting electrode **42** is attached to the non-conductive perforated member **40**. The perforated member contains a number of openings **21** through which a sacrificial layer (not shown) between the diaphragm and perforated member is etched during fabrication to form the air gap **20**

and which later serve to reduce the acoustic damping of the air in the air gap to provide sufficient bandwidth of the transducer. A number of openings are also made in the diaphragm 12 and the perforated member 40 to form a leakage path 14 which together with the compliance of the back chamber (not shown), on which the transducer will be mounted, forms a high-pass filter resulting in a roll-off frequency low enough not to impede the acoustic function of the transducer and high enough to remove the influence of barometric pressure variations. The openings 14 are defined by photo lithographic methods and can therefore be tightly controlled, leading to a well defined low frequency behavior of the transducer. The attachment of the perforated member 40 along the perimeter 43 can be varied to reduce the curvature of the perforated member due to intrinsic internal bending moments. The perimeter can be a continuous curved surface (FIGS. 1-3) or discontinuous, such as corrugated (FIG. 4). A discontinuous perimeter 43 provides additional rigidity of the perforated member 40 thereby reducing the curvature due to intrinsic bending moments in the perforated member 40.

Turning to FIGS. 5-7, an alternative embodiment of an acoustic transducer in accordance with the present invention is depicted. The transducer 50 includes a conductive diaphragm 12 and a perforated member 40 supported by a substrate 30 and separated by an air gap 20. The diaphragm 12 is attached to the substrate through a number of springs 11, which serve to mechanically decouple the diaphragm from the substrate, thereby relieving any intrinsic stress in the diaphragm. Moreover, the diaphragm is released for stress in the substrate and device package.

The lateral motion of the diaphragm 12 is restricted by a support structure 41 in the perforated member 40, which also serves to maintain the proper initial spacing between diaphragm and perforated member 40. The support structure 41 may either be a continuous ring or a plurality of bumps. If the support structure 41 is a continuous ring, then diaphragm 12 resting on the support structure 41 forms tight acoustical seal, leading to a well controlled low frequency roll-off of the transducer. If the support structure 41 is a plurality of bumps, then the acoustical seal can be formed by limiting the spacing between the bumps, or by providing a sufficiently long path around the diaphragm and through the perforations 21.

The conducting diaphragm 12 is electrically insulated from the substrate 30 by a dielectric layer 31. A conducting electrode 42 is attached to the non-conductive perforated member 40. The perforated member contains a number of openings 21 through which a sacrificial layer (not shown)

between the diaphragm **12** and the perforated member is etched during fabrication to form the air gap **20** and which later serves to reduce the acoustic damping of the air in the air gap to provide sufficient bandwidth of the transducer. A number of openings are made in the support structure **41** to form a leakage path **14** (FIG. 6) which together with the compliance of the back chamber (not shown) on which the transducer can be mounted forms a high-pass filter resulting in a roll-off frequency low enough not to impede the acoustic function of the transducer and high enough to remove the influence of barometric pressure variations. The openings **14** are preferably defined by photo lithographic methods and can therefore be tightly controlled, leading to a well defined low frequency behavior of the transducer. The attachment of the perforated member along the perimeter **43** can be varied to reduce the curvature of the perforated member due to intrinsic internal bending moments. The perimeter **43** can be smooth (FIGS. 5-7) or corrugated (FIGS. 8 and 11). A corrugated perimeter provides additional rigidity of the perforated member thereby reducing the curvature due to intrinsic bending moments in the perforated member.

In operation, an electrical potential is applied between the conductive diaphragm **12** and the electrode **42** on the perforated member. The electrical potential and associated charging of the conductors produces an electrostatic attraction force between the diaphragm and the perforated member. As a result, the free diaphragm **12** moves toward the perforated member **40** until it rests upon the support structure **41**, which sets the initial operating point of the transducer with a well defined air gap **20** and acoustic leakage through path **14**. When subjected to acoustical energy, a pressure difference appears across the diaphragm **12** causing it to deflect towards or away from the perforated member **40**. The deflection of the diaphragm **12** causes a change of the electrical field, and consequently capacitance, between the diaphragm **12** and the perforated member **40**. As a result the electrical capacitance of the transducer is modulated by the acoustical energy.

A method to detect the modulation of capacitance is shown in FIG. 9. In the detection circuit **100**, the transducer **102** is connected to a DC voltage source **101** and a unity-gain amplifier **104** with very high input impedance. A bias resistor **103** ties the DC potential of the amplifier input to ground whereby the DC potential "Vbias" is applied across the transducer. Assuming in this circuit a constant electrical charge on the transducer, a change of transducer capacitance results in a change of electrical potential across the transducer, which is measured by the unity-gain amplifier.

Another method to detect the modulation of capacitance is shown in FIG. 10. In the detection circuit **200**, the transducer **202** is connected to a DC voltage source **201** and a charge amplifier configuration **205** with a feedback resistor **203** and capacitor **204**. The feedback resistor ensures DC stability of the circuit and maintains the DC level of the input of the amplifier, whereby the DC potential "Vbias-Vb" is applied across the transducer. Assuming in this circuit a constant potential across the transducer, due to the virtual ground principle of the amplifier, a change of capacitance causes a change of charge on the transducer and consequently on the input side of the feedback capacitor leading to an offset between the negative and positive input on the amplifier.

The amplifier supplies a mirror charge on output side of the feedback capacitor to remove the offset, resulting in a change of output voltage "Vout." The charge gain in this circuit is set by the ratio between the initial transducer capacitance and the capacitance of the feedback capacitor. An advantage of this detection circuit is that the virtual ground principle of the amplifier eliminates any parasitic capacitance to electrical ground in the transducer, which otherwise attenuate the effect of the dynamic change of the microphone capacitance. However, care should be taken to reduce parasitic capacitances to minimize the of gain of any noise on the signal "Vb" and the inherent amplifier noise.

An embodiment of the raised microstructure **110** of the present invention is shown in FIGS. 13 and 14. The raised microstructure **110** comprises a generally circular thin-film plate or backplate **112** supported by a sidewall **114**.

The raised microstructure **110** is comprised of a thin film plate **112** of silicon nitride deposited on top of a sacrificial silicon oxide layer on a silicon wafer **116** using deposition and etching techniques readily and commonly known to those of ordinary skill in the relevant arts. The sacrificial silicon oxide layer has already been removed from the figure for clarity. The sidewall **114** of the raised microstructure **110** is attached at its base **118** to the silicon wafer **116** and attached at its opposite end to the plate **112**. The sidewall **114** is generally perpendicular to plate **112**, but it is noted other angles may be utilized between the sidewall **114** and the plate **112**.

FIG. 15 shows a plan view of the assembly of FIG. 13 with a surface of the sidewall **114** of the present invention shown in phantom. It can be seen that the sidewall **114** of the present invention as shown in FIGS. 13-15 is ribbed, forming a plurality of periodic ridges **120** and grooves **122**. In the preferred embodiment, the ridges **120** and grooves **122** are parallel and equally spaced, forming a corrugated structure. Furthermore, the preferred embodiment utilizes ridges **120** and

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grooves **122** of a squared cross section. The effect of corrugating the side wall in this manner is to create segments **124** of the sidewall **114** that are radial, as is the intrinsic tension **T** of the plate **112**. By making portions of the sidewall **114** radial, as is the tension **T**, the sidewall **114** is stiffened. It has been found that the sidewall **114** of the prior art, which is tangential to plate **112**, is easily bent as compared to the radial segments **124** of the present invention.

Other geometries than that shown in FIGS. 13-15 of the corrugations or ridges **120** and grooves **122** can be imagined and used effectively to increase the sidewall's **114** ability to resist moment **M** and the geometry depicted in the FIGS. 13-15 is not intended to limit the scope of the present invention.

For example, a generally annular geometry, generally triangular geometry or any combination or variation of these geometries or others could be utilized for the ridges **122** and grooves **124**.

In the preferred embodiment, the corrugations are radial and hence the sidewalls **114** are parallel to the tension in the backplate **112**. Furthermore, the sacrificial material is etched in such a way that the sidewalls **114** are sloped with respect to the substrate to allow good step coverage as the thin film backplate **112** is deposited.

While the specific embodiments have been illustrated and described, numerous modifications come to mind without significantly departing from the spirit of the invention and the scope of protection is only limited by the scope of the accompanying Claims.

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CLAIMS

WE CLAIM:

1. An acoustic transducer comprising:
 - a cover member having a planar surface with a plurality of perforations therein;
 - a substrate operably attached to said perforated member;
 - a diaphragm positioned between said cover member and said substrate, said diaphragm laterally movable within a plane parallel to said planar surface of said cover member;
 - a circuit operably coupled to said diaphragm to apply an electrical field in the space between said perforated member and diaphragm;
 - a circuit operably coupled to said diaphragm and responsive to changes in electrical capacitance between said cover member and said diaphragm; and
 - wherein the cover member includes a perimeter of attachment between said cover member and said substrate that is shaped to reduce the sensitivity of said cover member to intrinsic internal bending moments.
2. The acoustic transducer of claim 1 wherein said perimeter is corrugated.
3. The acoustic transducer of claim 1 wherein said cover member and said substrate define a lateral restraint.
4. The acoustic transducer of claim 1 wherein one or more indentations are made in said diaphragm to prevent stiction between said diaphragm and said substrate.
5. The acoustic transducer of claim 1 wherein said cover member includes a support structure having one or more openings to reduce sensitivity of said cover member to intrinsic internal bending moments.
6. The acoustic transducer of claim 1 wherein one or more mechanical springs are operably connected to said cover member and said diaphragm.
7. The acoustic transducer of claim 1 wherein one or more coincident openings are made in said diaphragm and said cover member to provide a low frequency pressure equalization path across said diaphragm.
8. The acoustic transducer of claim 1 wherein one or more non-coincident openings are made in said diaphragm and said cover member.

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9. The acoustic transducer of claim 1 wherein said cover member includes a support structure having one or more openings made therein to provide a low frequency pressure equalization path across said diaphragm.

10. The acoustic transducer of claim 1 wherein said cover member includes a support structure and said diaphragm is held in position against said support structure by electrostatic attraction forces generated between said diaphragm and said perforated member due to said electrical field.

11. The acoustic transducer of claim 1 wherein said diaphragm and cover member are made on a silicon wafer using photo lithographic techniques.

12. The acoustic transducer of claim 1 wherein said diaphragm and cover member are made from one or more materials consisting of carbon-based polymers, silicon, polycrystalline silicon, amorphous silicon, silicon dioxide, silicon nitride, silicon carbide, germanium, gallium arsenide, carbon, titanium, gold, iron, copper, chromium, tungsten, aluminum, platinum, palladium, nickel, tantalum and their alloys.

13. An acoustic transducer comprising:

a cover member having a planar surface with a plurality of perforations therein;

a substrate operably attached to said perforated member;

a diaphragm positioned between said cover member and said substrate, said diaphragm laterally movable within a plane parallel to said planar surface of said cover member;

a circuit operably coupled to said diaphragm to apply an electrical field in the space between said perforated member and diaphragm;

a circuit operably coupled to said diaphragm and responsive to changes in electrical capacitance between said cover member and said diaphragm; and

wherein said cover member includes a support structure having one or more openings made therein to provide a low frequency pressure equalization path across said diaphragm.

14. The acoustic transducer of claim 13 wherein said perimeter is corrugated.

15. The acoustic transducer of claim 13 wherein said cover member and said substrate define a lateral restraint.

16. The acoustic transducer of claim 13 wherein one or more indentations are made in said diaphragm to prevent stiction between said diaphragm and said substrate.

17. The acoustic transducer of claim 13 wherein said cover member includes a support structure having one or more openings to reduce sensitivity of said cover member to intrinsic internal bending moments.

18. The acoustic transducer of claim 13 wherein one or more mechanical springs are operably connected to said cover member and said diaphragm.

19. The acoustic transducer of claim 13 wherein one or more coincident openings are made in said diaphragm and said cover member to provide a low frequency pressure equalization path across said diaphragm.

20. The acoustic transducer of claim 13 wherein one or more non-coincident openings are made in said diaphragm and said cover member.

21. The acoustic transducer of claim 13 wherein the cover member includes a perimeter of attachment between said cover member and said substrate that is shaped to reduce the sensitivity of said cover member to intrinsic internal bending moments.

22. The acoustic transducer of claim 13 wherein said cover member includes a support structure and said diaphragm is held in position against said support structure by electrostatic attraction forces generated between said diaphragm and said perforated member due to said electrical field.

23. The acoustic transducer of claim 13 wherein said diaphragm and cover member are made on a silicon wafer using photo lithographic techniques.

24. The acoustic transducer of claim 13 wherein said diaphragm and cover member are made from one or more materials consisting of carbon-based polymers, silicon, polycrystalline silicon, amorphous silicon, silicon dioxide, silicon nitride, silicon carbide, germanium, gallium arsenide, carbon, titanium, gold, iron, copper, chromium, tungsten, aluminum, platinum, palladium, nickel, tantalum and their alloys.

25. A raised microstructure for use in a silicon based device, the raised microstructure comprising:

 a generally planar thin-film;

 a sidewall supporting the film;

 wherein the sidewall has at least one rib formed therein.

26. The raised microstructure of claim 25 wherein the sidewall is corrugated.

27. The raised microstructure of claim 25 wherein the rib has a generally arcuate cross section.

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28. The raised microstructure of claim 25 wherein the rib has a generally triangular cross section.
29. The raised microstructure of claim 25 wherein the rib has a generally rectangular cross section.
30. The raised microstructure of claim 25 wherein the thin-film comprises one plate of a silicon based capacitive transducer.
31. The raised microstructure of claim 25 wherein the thin-film comprises a rigid backplate of a silicon based microphone.
32. A silicon based electret microphone having a backplate comprising:
 - a generally planar thin-film;
 - a sidewall supporting the film;
 - wherein the sidewall has at least one rib formed therein.
33. The microphone of claim 32 wherein the sidewall is corrugated.
34. The microphone of claim 32 wherein the rib has a generally arcuate cross section.
35. The microphone of claim 32 wherein the rib has a generally triangular cross section.
36. The microphone of claim 32 wherein the rib has a generally rectangular cross section.
37. The microphone of claim 32 wherein the sidewall includes a plurality of ribs.
38. The microphone of claim 37, wherein the ribs are equally spaced about the sidewall.
39. A raised microstructure for use in a silicon based device, the raised microstructure comprising:
 - a generally planar element with a first thickness and a periphery;
 - a sidewall with a second thickness;
 - said sidewall supporting said planar element at said periphery above a substrate at a distance;
 - wherein said sidewall has a plurality of ribs formed therein.
40. The raised microstructure of claim 39 wherein said first thickness is small compared to the lateral extent of the said planar element.
41. The raised microstructure of claim 39 wherein said second thickness is approximately equal to the said first thickness.
42. The raised microstructure of claim 39 wherein said distance is large compared to said second thickness.

43. The raised microstructure of claim 39 wherein the ribs follow a periodic path of the periphery, inwards and outwards with respect to the centroid of the planar element.

44. The raised microstructure of claim 43 wherein the path is arcuate.

45. An acoustic transducer comprising:

 a cover member having a planar surface with a plurality of perforations therein;

 a substrate operably attached to said perforated member;

 a diaphragm positioned between said cover member and said substrate, said diaphragm laterally movable within a plane parallel to said planar surface of said cover member, wherein the cover member includes a perimeter of attachment between said cover member and said substrate that is shaped to reduce the sensitivity of said cover member to intrinsic internal bending moments.

46. The transducer of claim 45 including a circuit operably coupled to said diaphragm and responsive to changes in electrical capacitance between said cover member and said diaphragm.

47. The transducer of claim 45 including a circuit operably coupled to said diaphragm to apply an electrical field in the space between said perforated member and diaphragm

48. The acoustic transducer of claim 45 wherein said perimeter is corrugated.

49. The acoustic transducer of claim 45 wherein said cover member and said substrate define a lateral restraint.

50. The acoustic transducer of claim 45 wherein the diaphragm includes an indentation to prevent stiction between said diaphragm and said substrate.

51. The acoustic transducer of claim 45 wherein said cover member includes a support structure having an opening to reduce sensitivity of said cover member to intrinsic internal bending moments.

52. The acoustic transducer of claim 45 including a mechanical spring operably connected to said cover member and said diaphragm.

53. The acoustic transducer of claim 45 wherein the diaphragm and the cover member include coincident openings to provide a low frequency pressure equalization path across said diaphragm.

54. The acoustic transducer of claim 45 including a plurality of the coincident openings.

55. The acoustic transducer of claim 45 wherein said cover member includes a support structure having an openings to provide a low frequency pressure equalization path across said diaphragm.

56. The acoustic transducer of claim 45 wherein said cover member includes a support structure for supporting said diaphragm when the transducer is biased.

57. The acoustic transducer of claim 45 wherein said diaphragm and cover member are made on a silicon wafer using photo lithographic techniques.

58. The acoustic transducer of claim 45 wherein said diaphragm and cover member are made from one or more materials consisting of carbon-based polymers, silicon, polycrystalline silicon, amorphous silicon, silicon dioxide, silicon nitride, silicon carbide, germanium, gallium arsenide, carbon, titanium, gold, iron, copper, chromium, tungsten, aluminum, platinum, palladium, nickel, tantalum and their alloys.

59. An acoustic transducer comprising:

a substrate;

a cover member having a planar surface and a support structure;

a diaphragm positioned between said cover member and said substrate, said diaphragm laterally movable within a plane parallel to said planar surface of said cover member, wherein the support structure engages the periphery of the diaphragm when the transducer is biased, to maintain the spacing of the diaphragm from the cover member.

60. The transducer of claim 59 wherein the cover member includes a plurality of perforations.

61. The transducer of claim 59 wherein the support structure is continuous.

62. The transducer of claim 59 wherein the support structure comprises a plurality of bumps.

63. An acoustic transducer comprising:

a substrate;

a cover member having a planar surface and a support structure;

a diaphragm;

means for suspending the diaphragm from the substrate to permit free movement of the diaphragm within its plane, wherein the support structure engages the periphery of the diaphragm when the transducer is biased, to maintain the spacing of the diaphragm from the cover member.

64. The transducer of claim 63, wherein the suspending means comprises high compliance springs.

65. The transducer of claim 63 wherein the support structure is continuous.

66. The transducer of claim 63 wherein the support structure comprises a plurality of bumps.

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FIG. 1

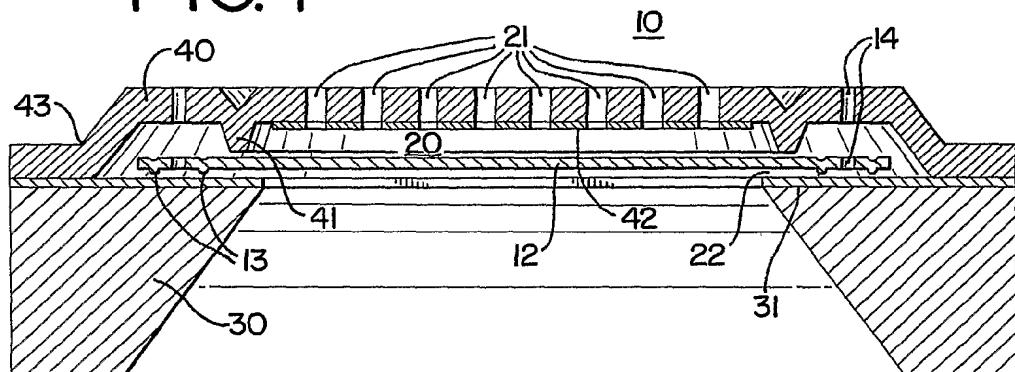
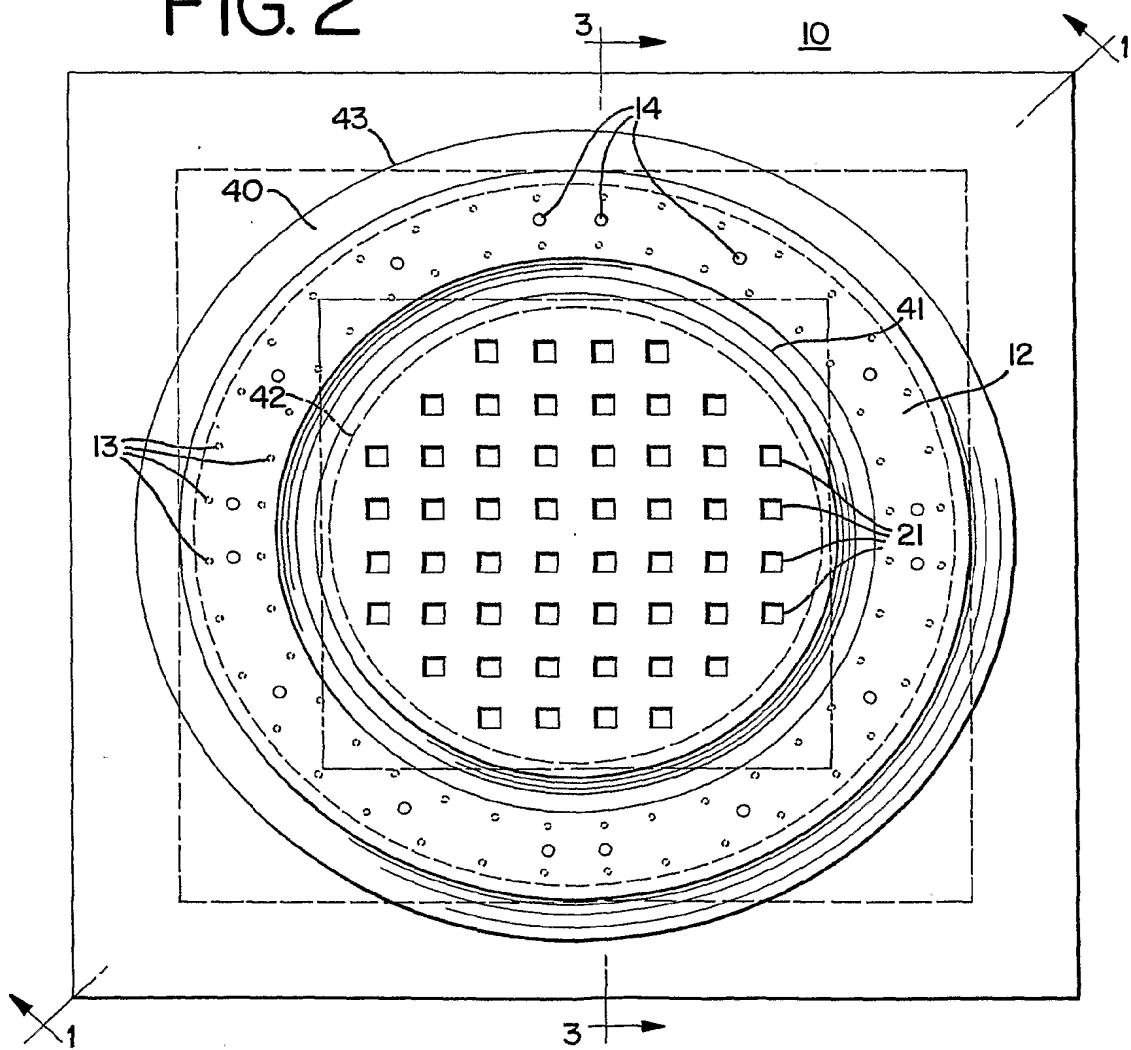


FIG. 2



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FIG. 3

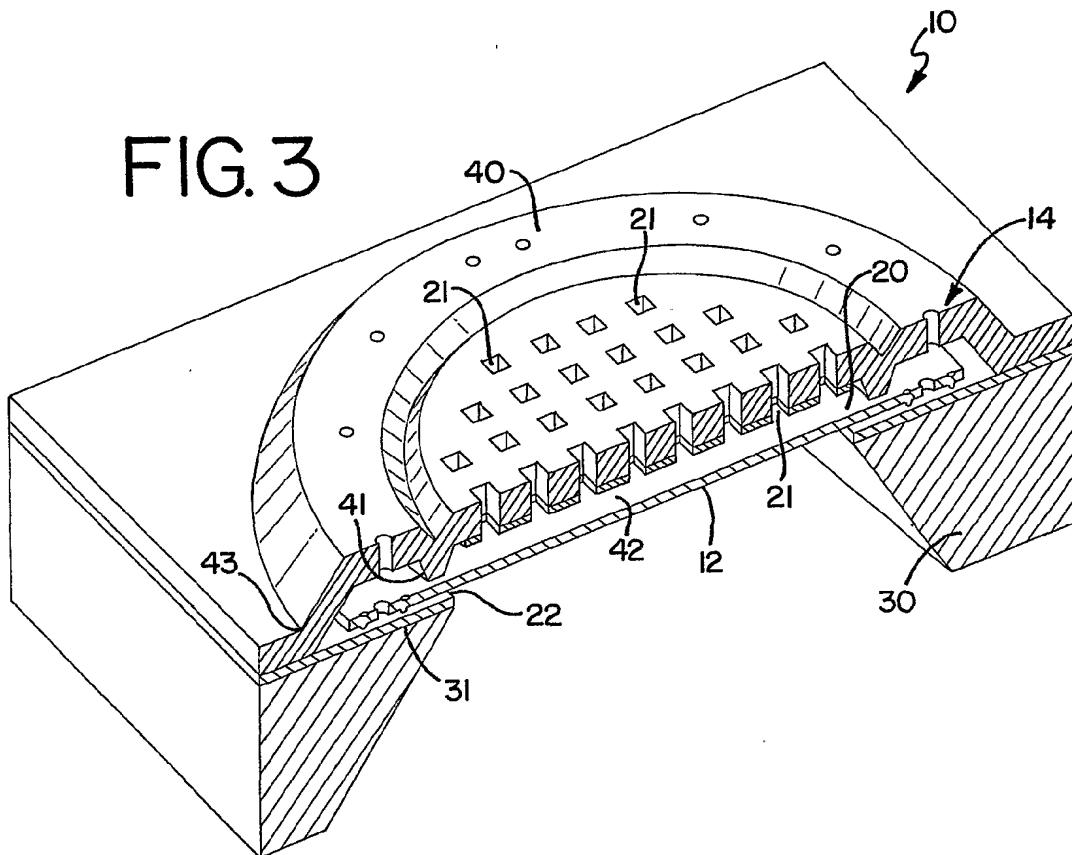
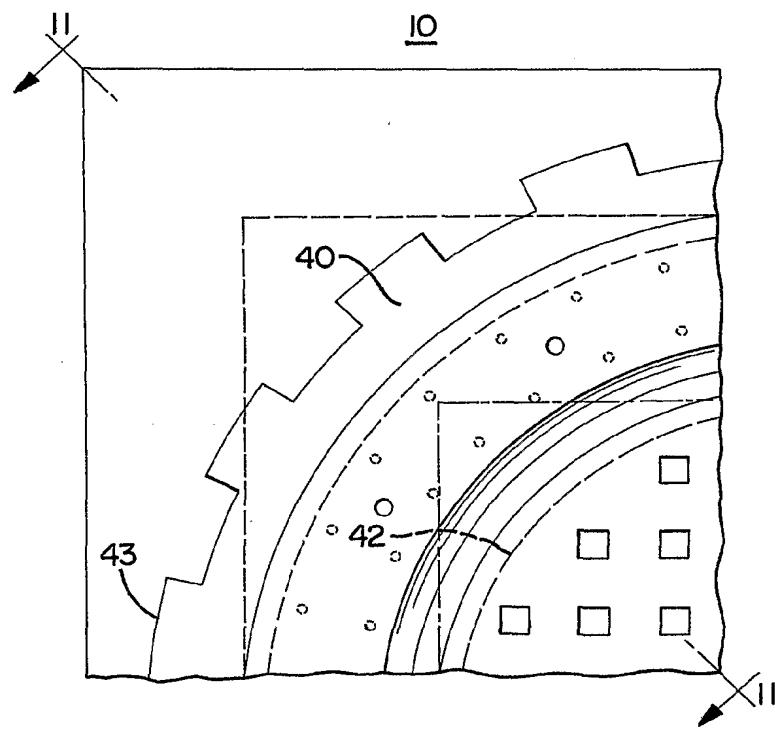


FIG. 4



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FIG. 5

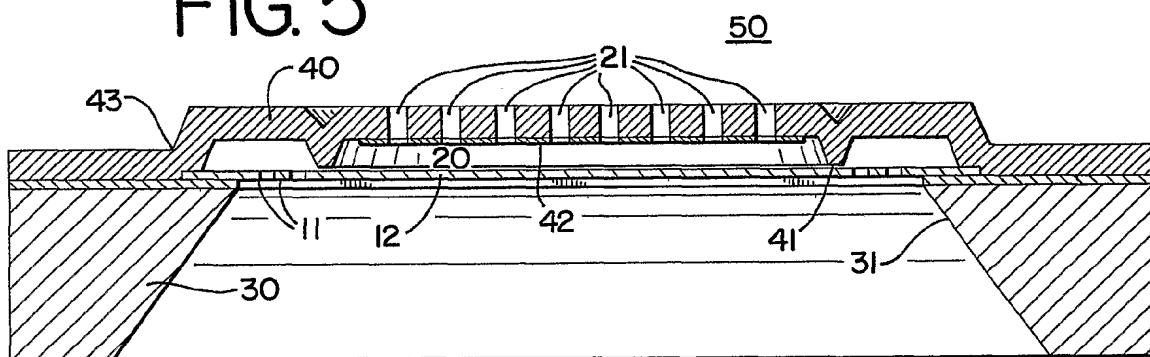


FIG. 6

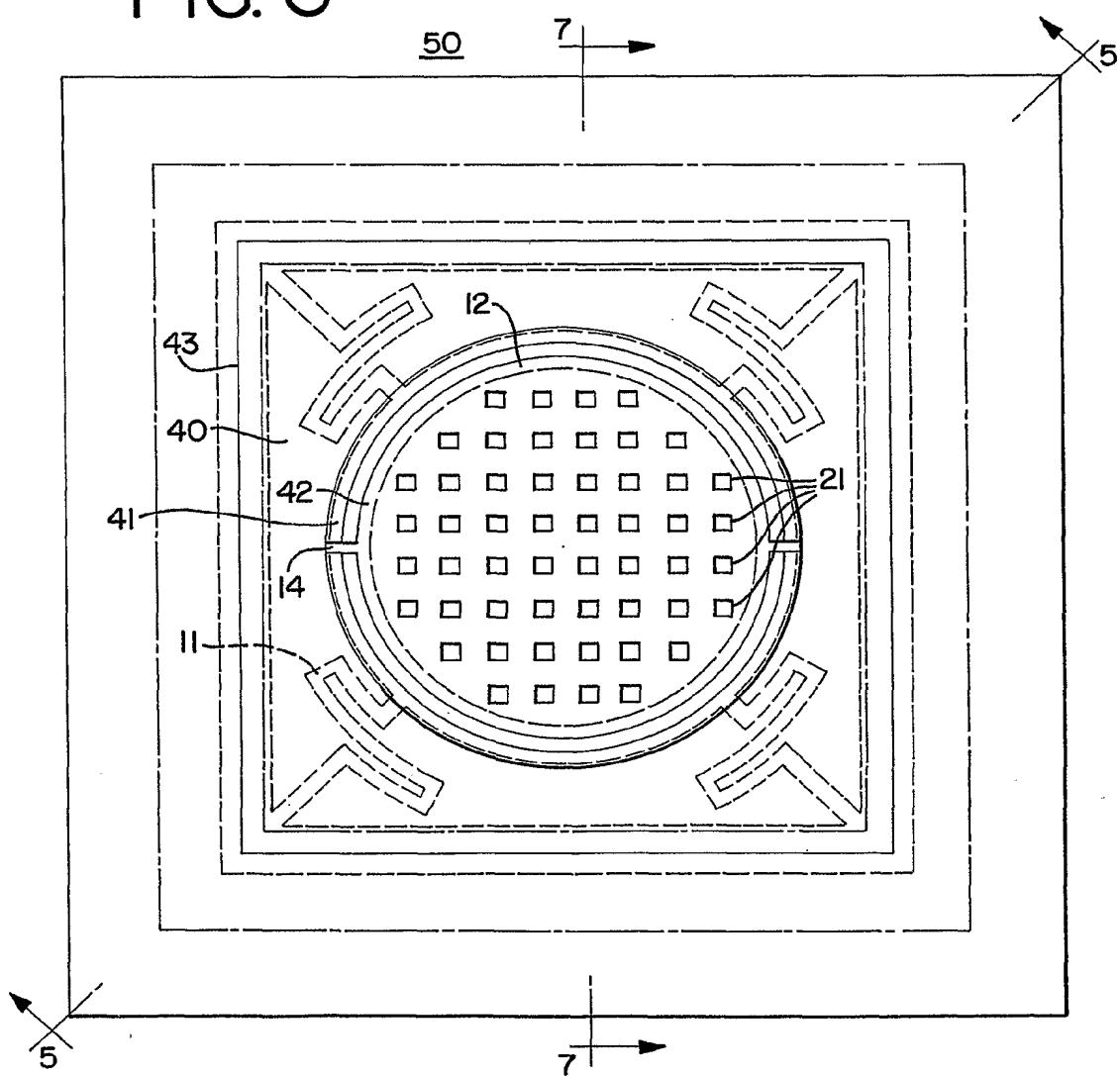


FIG. 7

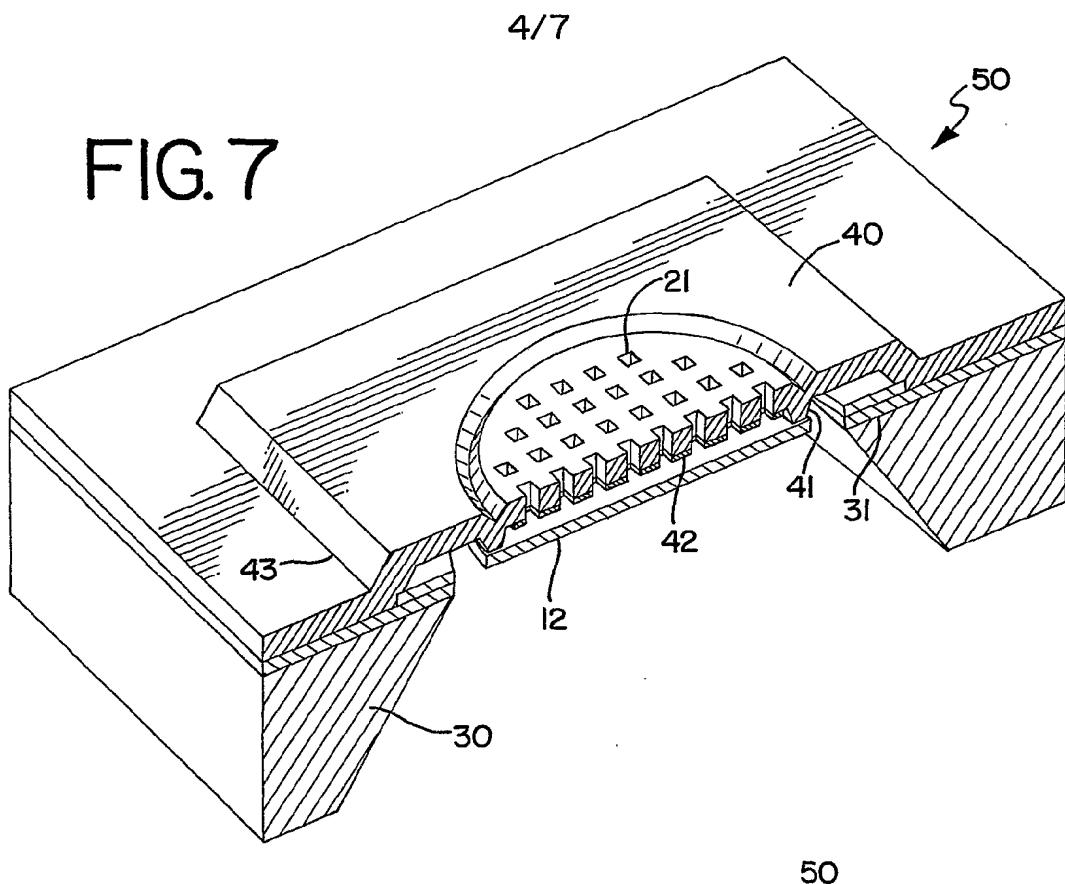
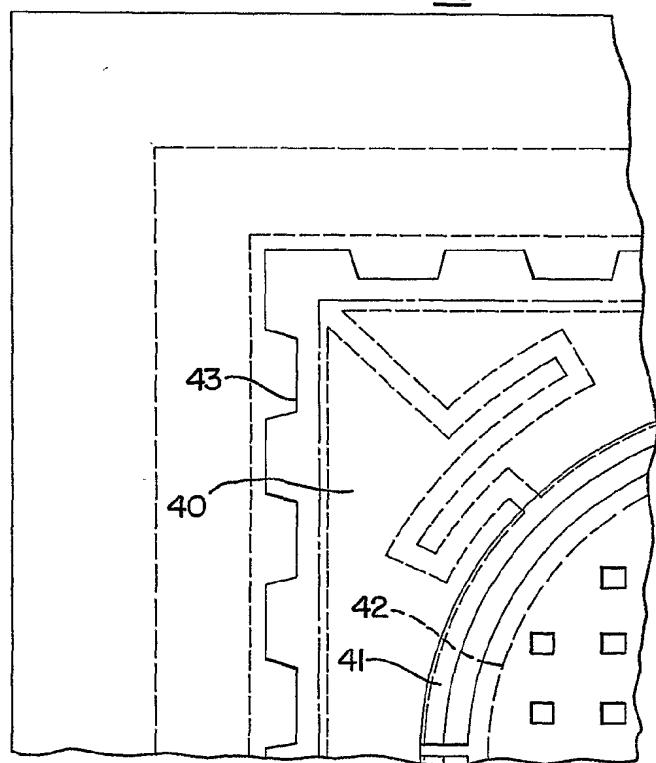


FIG. 8



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FIG. 9

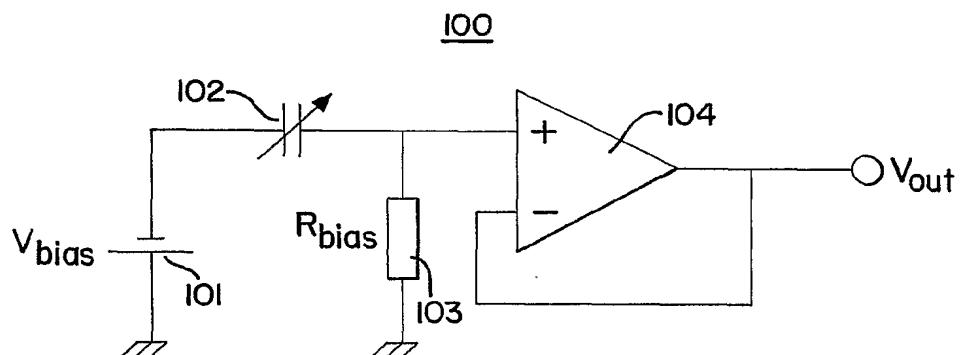
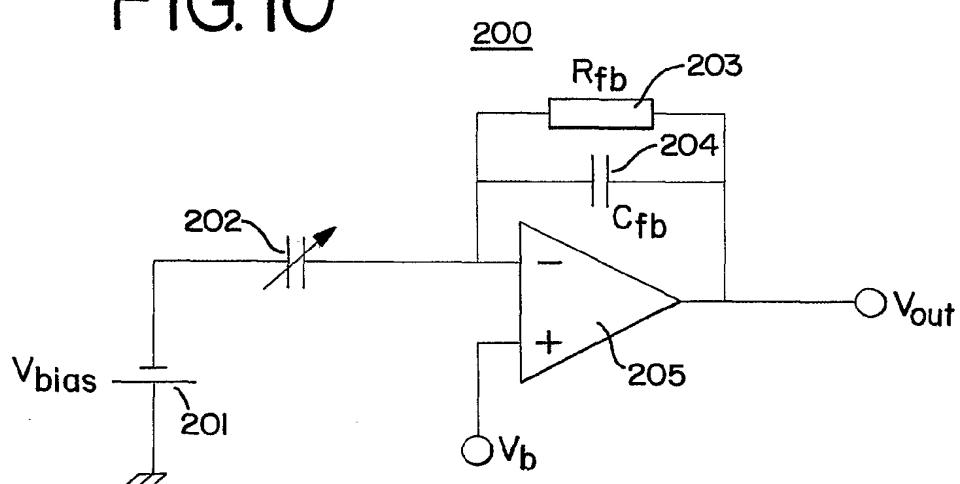
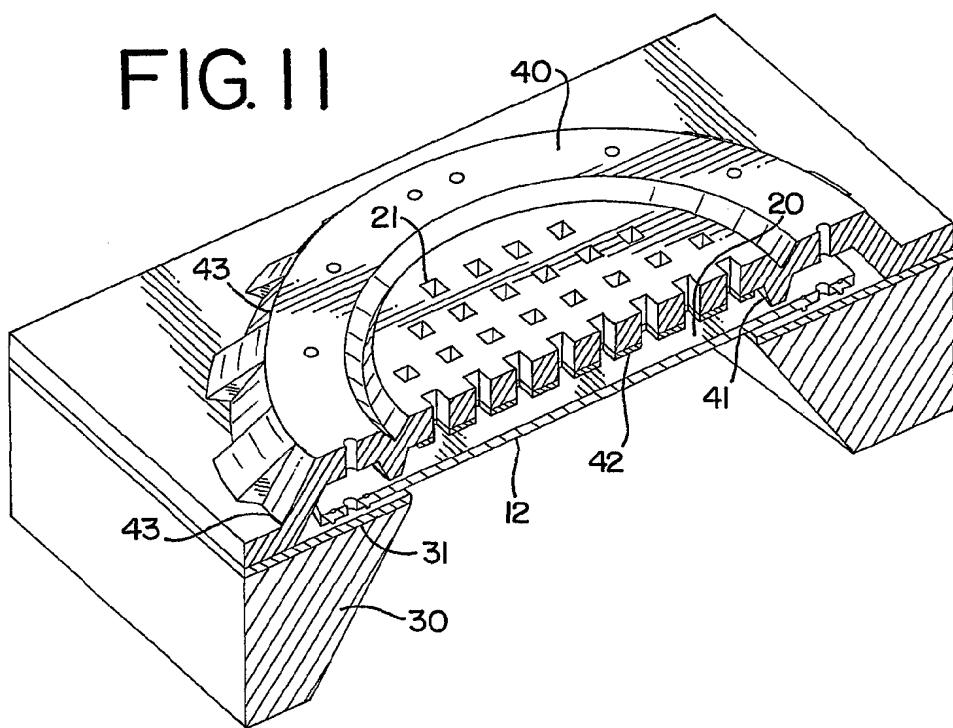
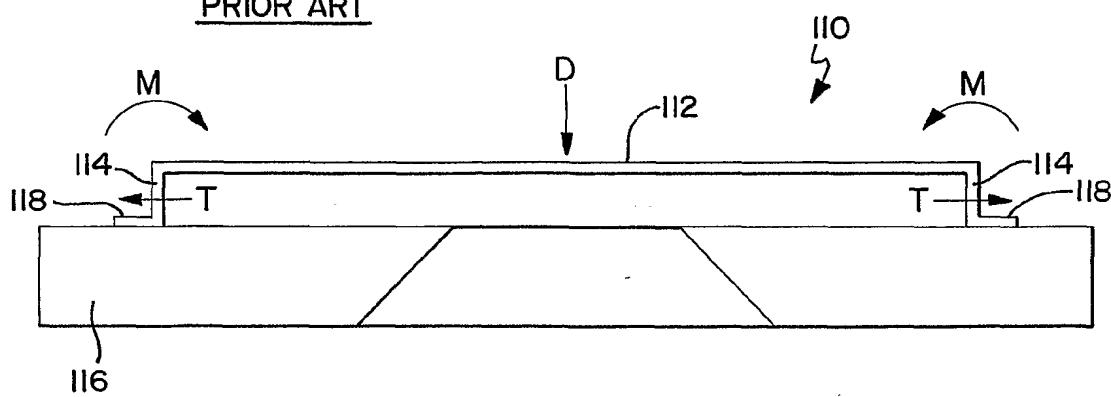


FIG. 10



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FIG. 11

FIG. 12
PRIOR ART

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FIG. 13

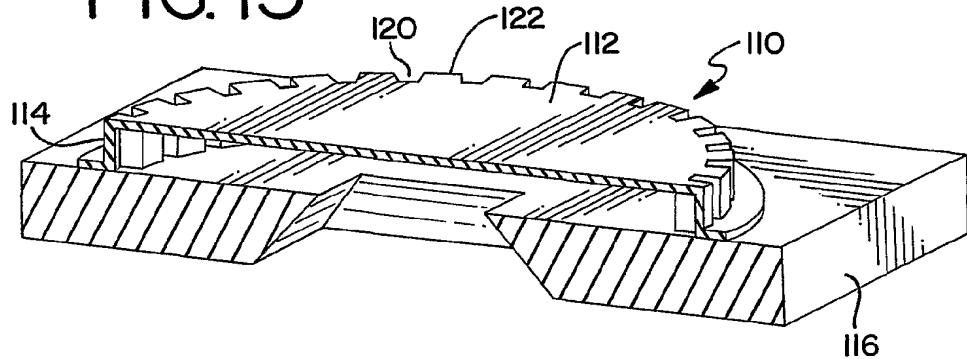


FIG. 14

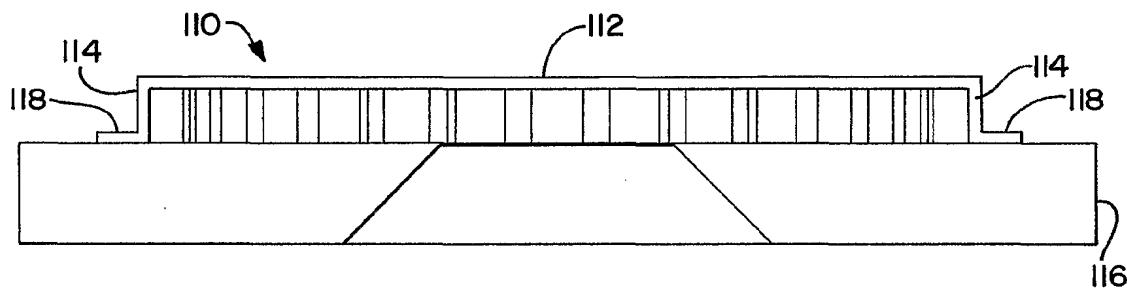
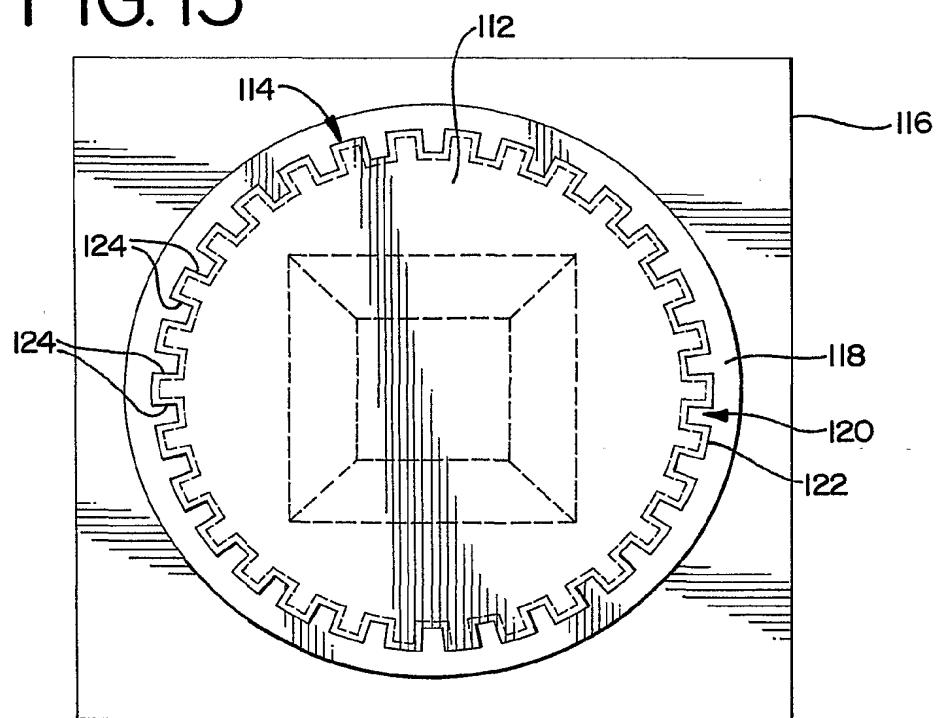


FIG. 15



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(72) Inventors; and

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(81) Designated States (national): AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EC, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

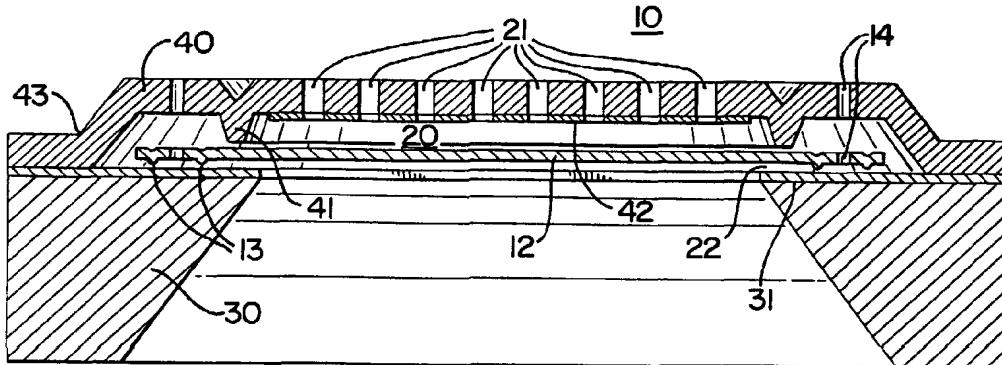
(84) Designated States (regional): ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, ML, MR, NE, SN, TD, TG).

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[Continued on next page]

(54) Title: MINIATURE BROADBAND TRANSDUCER



WO 02/015636 A3

(57) Abstract: Multiple embodiments of solid state micro-structures, such as a condenser microphone, are disclosed. According to one embodiment, the transducer a fixed perforated member, a freely movable diaphragm spaced from the perforated member, a support ring in the perforated member maintaining the proper spacing between the diaphragm and the perforated member near the perimeter; and compliant suspension springs allowing the diaphragm to rest freely on the support ring and yet mechanically decouples the diaphragm from the perforated member. According to another embodiment, a raised micro-structure is disclosed for use in a silicon based device. The raised micro-structure comprises a generally planar film having a ribbed sidewall supporting the film.



(88) Date of publication of the international search report:

24 October 2002

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/US 01/25184

A. CLASSIFICATION OF SUBJECT MATTER

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According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 H04R

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal, WPI Data, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	EP 0 561 566 A (MONOLITHIC SENSORS INC) 22 September 1993 (1993-09-22)	1,3,5-8, 10-12, 45-47, 49, 52-54, 57,58 2,4,9, 13-44, 48,50, 51,55, 56,59-66
A	column 2, line 50 -column 3, line 13 column 3, line 53 -column 6, line 40 figures ---- -/-	

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Date of mailing of the international search report

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PCT/US 01/25184

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	US 5 452 268 A (BERNSTEIN JONATHAN J) 19 September 1995 (1995-09-19) cited in the application column 1, line 60 -column 3, line 30 column 3, line 59 -column 5, line 40 -----	1-66
A	US 4 908 805 A (SPRENKELS ADRIANUS J ET AL) 13 March 1990 (1990-03-13) column 1, line 46 -column 4, line 54 column 5, line 13 -column 6, line 32 column 9, line 53 -column 10, line 21 -----	1-66

INTERNATIONAL SEARCH REPORT

Information on patent family members

International Application No

PCT/US 01/25184

Patent document cited in search report	Publication date	Patent family member(s)		Publication date
EP 0561566	A 22-09-1993	AU 3526093	A	23-09-1993
		CA 2092627	A1	19-09-1993
		DE 69325732	D1	02-09-1999
		DE 69325732	T2	27-04-2000
		DK 561566	T3	27-03-2000
		EP 0561566	A2	22-09-1993
		FI 931183	A	19-09-1993
		JP 7050899	A	21-02-1995
		NO 930970	A	20-09-1993
		US 5490220	A	06-02-1996
<hr/>				
US 5452268	A 19-09-1995	AU 2827195	A	07-03-1996
		CA 2197197	A1	22-02-1996
		EP 0775434	A1	28-05-1997
		JP 9508777	T	02-09-1997
		KR 232420	B1	01-12-1999
		WO 9605711	A1	22-02-1996
<hr/>				
US 4908805	A 13-03-1990	NL 8702589	A	16-05-1989
		GB 2212026	A , B	12-07-1989
		US 4910840	A	27-03-1990